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SHIELDING PROPERTIES AND EFFECTS OF WO_3 AND PbO ON MASS ATTENUATION COEFFICIENTS BY USING MCNPX CODE

H. O. TEKIN[a,d*], M. I. SAYYED[b], E. E. ALTUNSOY[c,d], T. MANICI[d]
[a]*Uskudar University, Vocational School of Health Services, Radiotherapy Department, Istanbul, Turkey*
[b]*Physics Department, University of Tabuk, Tabuk, Saudi Arabia*
[c]*Uskudar University, Vocational School of Health Services, Medical Imaging Department, Istanbul, Turkey*
[d]*Uskudar University, Medical Radiation Research Center (USMERA), Istanbul, Turkey*

In this study the shielding properties and effects of WO_3 and PbO particles on radiation mass attenuation coefficients have been investigated by using MCNPX (version 2.4.0) general purpose Monte Carlo code. The valiadation of Monte Carlo geometry has been provided by comparing the primary results with standart XCOM data for mass attenuation coefficients of WO_3 and PbO. A very good correlation between XCOM and MCNPX have been obtained. The valiadated geometry has been used for simulation of WO_3 and PbO doped concrete samples in different rates. The radiation mass attenuation coefficients for concrete samples doped by different percentages of PbO and WO_3 were calculated using MCNPX simulation for the five different energies 356 keV, 662 keV, 1173 keV, 1234 keV and 1333 keV.and half value layers (HVL) of modeled samples have been investigated. The results showed that effect of PbO in concrete sample caused to higher increase than WO_3 on mass attenuation coefficients in the same additiverates. It can be concluded that addition of PbO into concrete can be considered as another significant method than WO_3 to reduce radiation dose.

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Keywords: Mass Attenuation Coefficient, Radiation Shielding, Monte Carlo

1. Introduction

Radiation shielding and material investigation has become a major subject of increasing interest among different applications in which radiation being used such as medical applications, atomic energy and industrial applications. On the other hand, both kind of radiation such as direct and scattered radiations can be seriously dangerous to human health. Consequently, it is a significant issue toinvestigate radiation protection properties and features of new generation materials. This potential risk can be overcome bythree main procedures; time, distance and shielding. Radiation shielding mostly required against the ionizing radiations. The third has been allowing usage of new generationmaterials and various investigations for better radiation protection against ionizing radiation. The shielding technique related to gamma–rays energy and charge of the shielding material [1]. In comparison with other building materials used in radiation areas, concrete material has various advantage as a shielding material [2]. However, glass materials are one of the alternative shielding materials due to their transparent structure and can be adjusted by preparation techniques [3]. Thus, this kind of materials can be one of the alternative to concrete and can be used for the aim of gamma-ray absorption [4].Interaction of radiation with shielding materials can be described by some essential parameters like, the mass attenuation coefficient. Themass attenuation coefficient is one of themost important parameters for characterizing the penetration and diffusion of gamma-rays in any objective material [5]. Mass

* Corresponding author: tekin765@gmail.com

attenuation coefficients of investigated materials are determined by the transmission method according to Beer-Lambert's law:

$$\mu_m . x = \ln (I_0/I) \quad (1)$$

where I_o and I are the incident and attenuated photon intensity, respectively, μ_m ($cm^2 \cdot g^{-1}$) is the mass attenuation coefficient, and x is the thickness of the slab in equation 1 [6]. It is recognized that $WO_3$and PbO materials can be used as a shielding materials against to gamma-rays. Various studies on shielding properties of these materials found in literature. Dong et. al invstigated the gamma-ray shielding properties by PbO partial replacement of WO_3in ternary $60TeO_2$-(40-x)WO_3-xPbO glass system [7]. Chathima et.al studied on Bi_2O_3, PbO and BaO in silicate Glass System for development of gamma-rays shielding materials [8]. Tekin et.al investigated the Effects of micro-sized and nano-sized WO_3 on mass attenuation coefficients of concrete [9].The aim of the present paper is to investigate gamma-rays interactions with PbO and WO_3added concretes at different rates by calculating the radiation mass attenuation coefficients in a wide energy range 356 keV, 662 keV, 1173 keV, 1274 keV and 1333 keV by using MCNPX (version 2.4.0) Monte Carlo code. The concrete samples were seperately modeledaccording to the standards and doped by different percentages of PbO and WO_3particles such as %25, %50 and %75, respectively. In this study, performance of modeled concrete samples by different percentages of PbO and WO_3 on gamma-ray shielding are discussed.

2. Methods and Materials

2.1. MCNPX simulation code

In this study, MCNPX (version 2.4.0) has been used for determination of mass attenuation coefficients of differentconcrete samples by different percentages of PbO and WO_3on gamma-ray shielding. MCNPX is a general purpose Monte Carlo code used for modeling interactions of radiation with certain materials and tracking all particle at different energies. MCNPX is full three-dimensional and utilizes extended nuclear cross section libraries [10]. In addition, the obtained value of the mass attenuation coefficients were used to calculate the half value layer. It is found that MCNPX code has been used for different types of radiation interaction with materials based researches [11-16]. MCNPX input parameters such as cell card definitions, surface card definitions, material card definitions, position of each simulation equipments, definitions and features of energy sources have been defined in input file according to their properties. Radiation mass attenuation coefficient properties of concrete samplesdoped by different percentages of PbO and WO_3particles have been investigated since radiation loses energy as it passes through matter by some physical processes such as photoelectric effect, Compton scattering, and pair production. The intensity of photon decreases as the photon beam propagates through the concrete sample according to the Lambert-Beer law. By taking this rule into consideration, a total Monte Carlo simulation geometry has been defined in MCNPX code. Fig. 1 shows the defined cross-sectional geometry setup in MCNPX Monte Carlo code. As it can be seen from Fig. 1, radiation source has been located between lead (density=11.3 g/cm^3) collimators. The investigated attenuator concrete sample has been located at the end of the collimation. To obtain the radiation attenuation features of the investigated concretesample, a detection area has been defined below the attenuator material. MCNPX calculations were completed by using Intel® Core™ i7 CPU 2.80 GHz computer hardware. During the simulation study, the error rate has been observed less than 0.1% of the output file. To acquire absorbed dose amounts in the detection area, average flux tally F4 has been used. This type of tally mash gives the sum of average flux in cell.

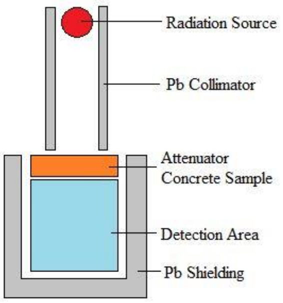


Fig. 1. Geometry setup of simulation

2.2. Validation study

In this study, gamma-rays sources and energy values were defined in data card of MCNPX input file. The concrete samples was defined by considering material features such as elemental mass fractions and densities. First, we modeled an ordinary concrete sample [6] by considering elemental mass fraction and density properties. The subsequent study was comparison of obtained results with standart XCOM [17] data. To validate the modeled geomerty, obtained results have been compared with standard XCOM data for pure concrete sample. The calculated mass attenuation coefficients by MCNPX agreed well with XCOM results. Thus, validated input code has been used for calculation of the radiation mass attenuation coefficients concrete samples doped by different percentages of PbO and WO_3 particles. The definitions of concrete samples have been done by considering the elemental mass fractions and densities of materials. Table 1. Gives the densities of the concrete samples. For the purpose of calculations of mass attenuation coefficients of each sample, 10^6 particles have been used during the simulation. The error rate of total simulation obtained in the output file less than 0.1%.

Table 1. Densities of the concrete samples

Sample	density (g/cm-3)
%100 Concrete	2,26
%75 Concrete + %25 PbO	4,0775
%50 Concrete + %50 PbO	5,895
%25 Concrete + %75 PbO	7,7125
%100 PbO	9,53
%75 Concrete + %25 WO_3	3,2702
%50 Concrete + %50 WO_3	4,71
%25 Concrete + %75 WO_3	5,935
%100 WO_3	7,16

2.3. Half value layer

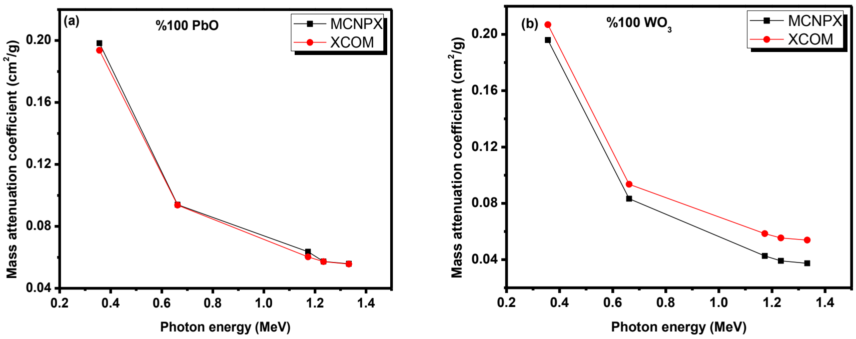
It is useful to express the attenuation of gamma rays in terms of a half value layer HVL. The HVL is the thickness of the concrete sample required to reduce the intensity of incident photon to 50% of its initial value [18]. The following relation was used to calculate the HVL for the selected concrete samples [19, 20]:

$$HVL = \frac{0.693}{\mu} \quad (2)$$

where μ is the linear attenuation coefficient (mass attenuation coefficient multiply by the density of concrete sample).

3. Results and discussion

The radiation mass attenuation coefficients for concrete samples doped by different percentages of PbO and WO3 were calculated using MCNPX simulation for the five different energies 356 keV, 662 keV, 1173 keV, 1234 keV and 1333 keV. The additiverates of WO_3 and PbO have been defined as %25, %50 and %75, respectively. In addition to mixed compounds, we calculated the radiation mas sattenuation coefficients for pure WO_3 and PbO using MCNPX simulation and XCOM software in order to test the validity of the MCNX code used in this work. The comparisons of results are shown in Fig.2 for PbO (a) and WO_3 (b), respectively. Fig. 2 shows that there is a good agreement between mass attenuation coefficient values, which are obtained from both MCNPX code and XCOM software. However, we obtained the slight differences. This could be due to deviations from narrow beam geometry in thesource-detector regulations. The calculated mass attenuation coefficients for different rate of PbO and WO_3 in concrete samples as a function of photon energy are shown in Fig. 3 and Fig.4. It can be seen that the mass attenuation coefficients decreased with increasing photon energy. Besides, at low photon energies (i.e. 356 keV, 662 keV) the mass attenuation coefficient reduces quickly due to the dominance of photoelectric effect; while at 1173 keV, 1234 keV and 1333 keV, Compton scattering and pair production phenomena are dominant [21]. Furthermore, from Fig. 3 and Fig. 4 it is clearly observed that the mass attenuation coefficients increased with increasing the concentration of PbO and WO3 in concrete samples. Hence, for an improved shielding effectiveness, a larger of PbO and WO3 content would be required. It is worth noting that the effect of PbO in concrete sample caused to higher increase than WO_3 on mass attenuation coefficient in same additiverates. It means that comparatively concrete samples doped by PbO have good radiation shielding properties than concrete doped by WO_3. It can be seen from Fig.3 and Fig.4 that slopes of the curves are slightly different from eachother. The reason of difference is due to the dominance of paritial interaction processes in different energy regions. The inclinations of the curves are different at different energies due to the dominance of fractional interaction processes in energy regions under consideration. The effectiveness of gamma ray shielding is described in terms of another important quantity which is half value layer (HVL). The results of the mass attenuation coefficient obtained by MCNPX code were then used to evaluate the HVL of the concrete samples doped by PbO and WO_3concretes to assess their shielding ability. Fig 5 and Fig 6 show the variation of HVL with PbO and WO_3 content in concrete samples. From the observation the values of HVL increased with increasing the gamma ray energy because to decrease the intensity of incident photon to 50% of its initial value, , more thickness of target will be required. In addition, the increase in PbO and WO_3 content in concrete sample decreases HVL, thus the shielding effectiveness is found to be higher than of pure concrete (i.e. without PbO or WO_3 additiverates). The HVL of the concrete samples doped by different percentages of PbO and WO_3were plotted and compared with the values of Ilmentite–Limonite concrete, hematite-serpentine and barite concretes[22] at 662 keV as shown in Fig. 7. It is seen that the HVL of the concrete samples decreased with the increase of PbO and WO_3 content, and this may attribute to the increase in the mass attenuation coefficient and density. In addition, it is clear from Fig. 7 that HVL for the concrete doped by PbO are lower than its corresponding value for concrete with same percentage of WO_3. It means that concrete doped by PbOare better in gamma ray shielding than concretes doped by WO_3.According to Fig 7, when the WO_3 and PbO concentration of 25 mol%, the radiation shielding has been found to be equal to hematite–Serpentine concrete and barite concrete respectively. In addition, the radiation shielding properties for the concrete samples doped by 50 and 75% of PbO and WO_3 are better than those of Ilmentite–Limonite concrete, hematite-serpentine and barite concretes.



(a) (b)

Fig. 2. The MCNPX results and XCOM results for mass attenuation coefficients for the (a) PbO and (b) WO_3

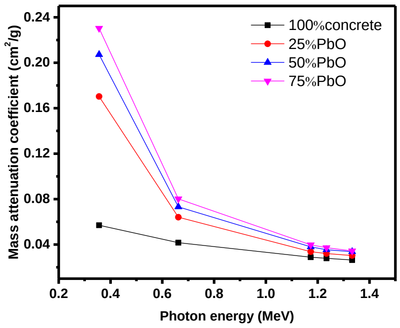


Fig. 3. The calculated mass attenuation coefficients for investigated PbO doped concrete samples

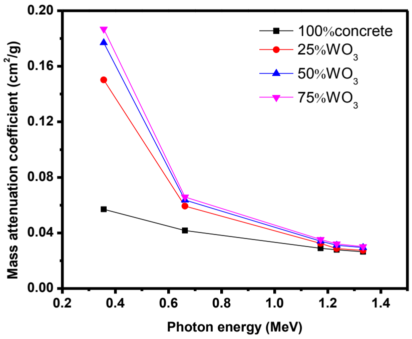


Fig. 4.The calculated mass attenuation coefficients for investigated WO_3 doped concrete samples

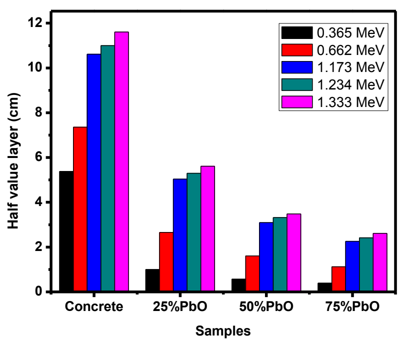


Fig. 5. Variation of half value layer with PbO content in concrete samples

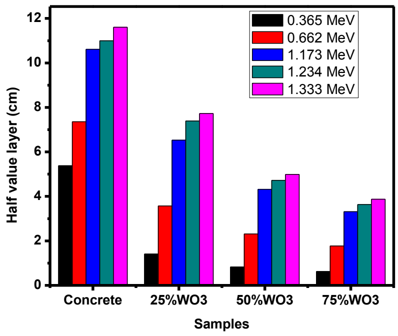


Fig. 6. Variation of half value layer with WO_3 content in concrete samples

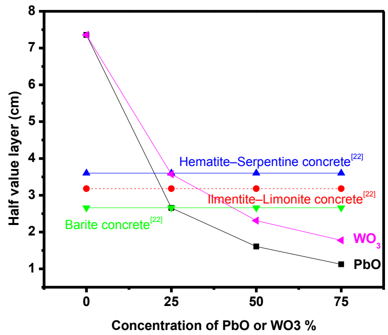


Fig. 7. The half value layer of concrete samples doped by PbO and WO_3 in comparison to some standard shielding concretes at 662keV

4. Conclusion

This study presents the effect of PbO and WO_3 materials on mass attenuation coefficients of concrete. It can be concluded that each PbO and WO_3 increment in concrete sample has caused the increment on mass attenuation coefficients of concrete. Certainly, additive rate of PbO and WO_3 also affected to mass attenuation coefficient values. It is clear that effect of PbO in concrete sample caused to higher increase than WO_3 on mass attenuation coefficients in the same additiverates. The reason of this difference can be due to difference of densities between PbO and WO_3. It is obvious that higher values of PbO or WO_3 in the concrete sample will improve the radiation shielding properties in terms of mass attenuation coefficient and half value layer.

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